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Review

State of the art and future developments of measurement applications on smartphones

P. Daponte, L. De Vito, F. Picariello *, M. Riccio

Department of Engineering, Laboratory of Signal and Measurement Information Processing, University of Sannio, Piazza Roma, 82100 Benevento, Italy

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ABSTRACT

The modern smartphones contain different sensor technologies, so they can be used as stand-alone measurement instruments on a wide range of application domains. The paper deals with a survey of measurement applications based on smartphones. In the first part, the evolution of mobile phone technologies, including the sensors and mobile networks developments, is presented. Then, in order to highlight the sensors and the communication capabilities, the architectural overview of the hardware and software technologies, which are available on latest series of smartphones, is reported and discussed. A review of measurements applications using the smart sensors and the communication interfaces available on smartphones, it is also presented. A classification of smartphone applications, which looks the smartphone as a handheld measurement instrument, is presented. In the last part, the integration of augmented reality to the measurement applications and new type of measurement systems, having a smartphone as processing support, is presented.

Contents

* Corresponding author. Tel.: +39 3881966423.
E-mail addresses: daponte@unisannio.it (P. Daponte), devito@unisannio.it (L. De Vito), fpicariello@unisannio.it (F. Picariello), riccio@unisannio.it (M. Riccio).

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1. Introduction

In the everyday experience, it is necessary to make measurements. Anytime one interacts with the environment around, he/she is making measurements of physical quantities. For this reason, it is important that measurements are available as friendly as possible for specialized and non-specialized people. A measurement is available if the measurement system is accessible and easy to use. For the everyday experience, a usable measurement system has the following features: (i) non-invasive, (ii) user friendly, and (iii) portable. A modern smartphone allows measuring of different physical quantities directly from its embedded sensors, e.g. three-axis accelerometer, three-axis magnetometer, barometer, light sensor, and so on. Moreover, the smartphone can communicate with other apparatuses (e.g. wireless sensor nodes, data acquisition boards, etc.) through wireless interfaces, such as Bluetooth, Wi-Fi and Near Field Communication (NFC). Thanks to these technologies, the smartphone is candidate to be considered as a measurement system, too.

The statistical data available on [1] present the United States (US) smartphone users and penetration on the market. In 2010, the US smartphone users were 60.2 millions, the 26.0% of mobile phone users and the 19.4% of population. Last year, the number of smartphone users was 106.7 millions, the 44.0% of mobile phone users and the 33.8% of population. In 2015 the number of smartphone users is expected to be around 148.6 millions, the 58.0% compared to mobile phone users and the 45.6% of US population. The smartphones are becoming even more popular and their market is expanding continuously.

In time, sensing applications have been developed in order to operate at multiple scales, from personal sensing to global sensing [2]. In [3], the authors classify sensing applications on smartphone in participatory sensing, when the user is directly involved in the sensing action and opportunistic sensing, when the user is not involved in the sensing action. In this way, many smartphone applications have been developed to implement sensing systems [4–6] and different researchers have been focused their works on the development of systems that use the smartphone as a sensing device [7,8].

In this paper, applications, where the smartphone is described from the point of view of measurements, are presented. Furthermore, a new classification of smartphone applications, which looks the smartphone as a handheld measurement instrument, is presented. In order to highlight the hardware and the software capabilities for using the smartphone in measurement applications, the smartphone technology is described. A new user interface for measurement application, based on mobile augmented reality, is described, too.

After the introduction, the paper is organized as follows. Section 2 offers a brief history of mobile phones, with the evolution of the hardware and mobile network. In Section 3, in order to highlight the hardware capabilities of smartphone as measurement instrument, an overview on the smartphone architecture is presented. Section 4 describes the sensors integrated in a modern smartphone, highlighting the hardware of the iPhone 5. In Section 5, different operating systems for smartphone are discussed. Section 6 describes the smartphone as a handheld measurement system. In Section 7, a survey of measurement applications using the sensors integrated on the smartphone is presented. Section 8 describes applications where the smartphone communicates with external equipment in order to measure physical quantities. The augmented reality on smartphone is presented on Section 9. Finally, Section 10 deals with the future developments of measurement applications on smartphones.

2. The evolution of mobile phones

In the last 20 years, mobile technologies had an exponential growth due to the development of new network capabilities, the integration of sensors on mobile phones and the introduction of more communication interfaces, as it is shown in Fig. 1.

The second generation networks (2G) are the first digital mobile networks at the global level. The Global System Mobile (GSM) network was released in 1991 and it is the first 2G network [9–11]. The Nokia 1011 is the first GSM Nokia mobile phone and the microphone is the main embedded sensor, which is used for vocal communication [12].

The High Speed Circuit Switched Data (HSCSD) was developed in the 1998 [11]. This allows a communication with different data rates using the same physical layer of the GSM technology and it uses multiple channels per single connection [13]. In the same period, the Nokia 8810 was the first phone without an external antenna and with the infrared communication interface [14].

In 1999 appeared the 2.5G networks, such as General Packet Radio Service (GPRS), which are an extension of 2G networks [11]. In this year, different technologies for mobile phones were developed. A phone called *Benefon Esc!* was the first GPS integrated mobile phone [15]. The first mobile phone with MP3 music capabilities was the Samsung SPH-M100, and the first mobile phone to offer a WAP browser supporting Internet and Web applications such as email was the Nokia 7110 [16].

In 2000, the 2.75G, known as Enhanced Data rates for GSM Evolution (EDGE), has been developed [11,17]. In the same period of time the first mobile phone having on a 110 kpixel CMOS camera, called Sharp J-SH04, was developed [18]. In 2001, the first Bluetooth v1.0b capable phone, Ericsson T39 was born [19]. In the same year, the third generation (3G) network have been developed [11]. 3G permits video calls and wireless broadband data transmission